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Sandstrom, Vilma

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Linking country level food supply to global land and water use and biodiversity impacts: the case of Finland

Vilma Sandström[1]*, Pekka E. Kauppi[1], Laura Scherer[2], Thomas Kastner[3]

[1] University of Helsinki, Faculty of Biological and Environmental Sciences, Department of Environmental Sciences, P.O. Box 65, Viikinkaari 2a, 00014 University of Helsinki, Finland

[2] Institute of Environmental Engineering, ETH Zurich, John-von-Neumann-Weg 9, 8093 Zurich, Switzerland

[3] Institute of Social Ecology Vienna, Alpen-Adria Universität Klagenfurt, Wien, Graz, Schottenfeldgasse 29, A-1070 Vienna, Austria

* Corresponding author

E-mail: vilma.sandstrom@helsinki.fi

Abstract

The agricultural products consumed in Europe are increasingly grown on foreign farms. We analyze the imports of food and feed crops to Finland from 1986 to 2011 by products and by their geographic origin drawing a link to environmental impacts. The share of foreign crops consumed in Finland nearly doubled in the study period. The imports increased especially with commodities that could also be produced domestically. While the production of food increasingly shifted abroad, also the exports from Finland increased. More than 90% of the blue water of the Finnish crop supply came from foreign water resources. We map the results of land and water use together with their impacts on global biodiversity, and show that most of the land and water use related biodiversity impacts (> 93%) associated with the Finnish food consumption are related to the imports and therefore taken place outside the Finnish borders. The use of multiple environmental indicators can help identifying products and spatial hotspots associated with the most severe environmental

impacts of the Finnish crop imports contributing to a more holistic decision-making and the promoting of sustainable food consumption both domestically and globally.

Keywords

International trade, food supply, land use, blue water consumption, biodiversity impacts

1. Introduction

Global trade has dramatically affected the geographical patterns of production in relation to consumption (Peters and Hertwich, 2008). Regarding agriculture, trade makes it possible to meet countries' food demand by foreign production, while at the same time outsourcing environmental impacts. About 23% of all the food produced for human consumption is traded internationally (D'Odorico et al., 2014). The international trade of agricultural products continues to increase (Kastner et al., 2014a) promoting food availability in various parts of the globe (Porkka et al., 2013). However, the complex pathways of trade hamper transparent analyses of the effects of food production on land use, biodiversity and fresh water resources. The increase in trade affects virtually all efforts to promote sustainable agriculture and need to be ever more addressed in scientific research.

At the global scale trade contributes to a more effective global food system when food is produced in areas with higher resource use efficiency such as higher yields (Kastner et al., 2014a) or improved water productivity (Hoekstra and Chapagain, 2008). Higher productivity can, however, increase overall consumption levels if it means lower prices for products with elastic demand. Also, agricultural intensification often requires heavier use of fertilizers and pesticides that can have implications to the environment. Trade can as well be a way of displacing environmental impacts from consumers to producers (Meyfroidt et al., 2010). For example, over the period 1990-2008 the crop and livestock imports of the EU countries affected significantly the rate of global deforestation (Cuypers et al., 2013). Dependency on international trade impacts countries' food security and makes them more susceptible to disturbances outside their borders (Suweis et al., 2015). Land and water grabbing has emerged as a new way of globalized agriculture when countries and corporations acquire foreign land and the associate fresh water resources to sustain their food and biofuel consumption having implications to food security both in the producing and the exporting countries (Rulli et al., 2013).

Quantifying the implications of agricultural globalization is fundamental to understanding how to sustainably meet growing local and global food demands (MacDonald et al. 2015, Foley et al. 2011). Telecouplings (Liu et al., 2013) and land teleconnections (Yu et al., 2013) form the analytical framework to quantify the socio-economic and environmental interactions among coupled human and natural systems over distances. Teleconnections can be defined as the links between international demand and the local environmental impacts caused by the production of traded goods. There are various methods to assess the land and water embodied in international trade, and they can be divided into three categories, based on the input data (Bruckner et al., 2015). Environmental-economic accounting (input–output analysis) tracks embodied resources in monetary values and physical accounting uses physical quantities as their input value. Hybrid accounting mixes these two to form a combination of both. All methods include uncertainties and their results differ, even in the extent that the choice of method can impact the directionality of the results, e.g. whether a country is a net exporter or net importer of land use (Kastner et al., 2014b; MacDonald et al., 2015). Physical accounting enables higher levels of detail for crop and livestock products, allows specific allocation of land use to production based on the reported national yields and avoids distortions in value-to-weight ratios (Bruckner et al., 2015). The disadvantages of physical accounting are related to its limited ability to handle supply chains of highly processed products, especially from non-food sources, such as textiles.

The environmental implications of the agricultural globalization can be assessed using various different metrics such as nutritional value, land use, irrigation water use or other ecological indicators such as, impacts to biodiversity. The choice of the metric can lead to divergent interpretations of trade relations and as a consequence contrasting policy suggestions, which highlights the importance of assessing multiple metrics (MacDonald et al., 2015).

This paper presents a national study of the displacement effects of trade based on physical accounting. An earlier study reported increased imports and exports between Finland and the global food markets over the period 1961 - 2007 (Sandström et al., 2014). Here we include data until 2011 and, more importantly, quantify the environmental impacts of the foreign crops consumed in Finland. Located in boreal northern Europe, Finland must cope with agricultural production at its climatic margins. Global trade can mitigate the climatic constraints and risks of the Finnish food system, but there are both advantages and drawbacks when increasing the dependency of foreign trade. One of the negative sides is the displacement of environmental impacts.

Previous studies have analyzed environmental impacts of Finnish imports using methods such as ecological or water footprint calculations (WWF Finland, 2012) or input-output models (Koskela et al., 2011; Mäenpää and Siikavirta, 2007) or a combination of both (Mattila et al.,2011). Sandström et al. (2014) described the development of imports and exports across the borders of Finland. However, none of the earlier approaches focused on the displaced environmental impacts taking into account the complex trade flows to trace the original production country of the imports consumed in Finland, which is the motivation of our analysis. In addition, this paper explicitly addresses land use, freshwater consumption and biodiversity impacts related to both land and water use in the production countries.

We focus on the agricultural products consumed in Finland including crops used as animal feed, and also including certain non-food crops, which contribute to the total cropland required. The objective of this paper is to present a country level case study and to investigate the development of agricultural imports over time, identify the domestic and foreign production regions for these products and analyze the environmental impacts caused by the production. The environmental pressure occurring at the production site is assessed with three indicator variables: first the area (in hectares) of cropland assigned to the Finnish food supply, second the quantity of fresh water used for cropland irrigation (=blue water), and third the biodiversity impacts caused by the land and water use in the production country.

2. Methods and data

2.1 Agricultural data

Our analysis is based on physical accounting. Estimates in tons were converted into estimates of resource use to illustrate the pressure on the environment related to the Finnish food supply. We use the information of agricultural trade of almost 450 secondary crop products converted into 132 primary products. In order to convert the processed products into primary products, conversion factors were used that were derived from the dry matter contents using standard factors of water contents (Haberl et al., 2007). Not all the products analyzed contribute to human food. For instance, some products were included such as flax, jute, manila, tobacco, rubber and palm oil that have also uses apart from food or feed. Detailed list of the primary crops included in the analysis can be found in Table S1. The method includes also the crops used for animal feed embedded in the animal products consumed in a country. The national level feed use data were obtained from the FAOSTAT commodity balances (FAO, 2016). A detailed description of the methodology to assess the feed use embedded in the animal products can be found from Kastner et al. (2014a). The input data are presented in tons of product that are available from the United Nations' Food and Agricultural Organization statistic database FAOSTAT (FAO, 2016) from 1986 to 2011.

2.2. Trade analysis

This method was developed by Kastner et al. (2011). The production of a country in this analysis is either consumed or exported. Analogously, the domestic consumption is supplied by domestic production or imports. The origin of agricultural products in the Finnish food supply was traced through trade matrices that are formed based on the information of the bilateral trade between Finland and the importing countries. Countries that report trade with Finland are not always countries where the crops were cultivated. Instead they "re-export" (often in processed form) products they previously imported themselves. In global level the re-exports account for 8 % of all the trade volumes analyzed (in terms of calories), and their exclusion would result in a misattribution of embodied resource use (MacDonald et al., 2015). To account for this we employ the approach proposed by Kastner (2011). The approach assumes that the exports of a country are proportionally made up by domestic production and imports (according to the country of origin). Based on this assumption, and the production and bilateral-trade data for all countries, the production countries are identified. A more detailed description of the method is given by Kastner et al. (2011 and 2014a). The results from 1986 to 2009 of trade at the global scale were published in Kastner et al. (2014a). This article investigates Finland in more detail, updating the data until the year 2011. Countries were aggregated into regions following the division by Kastner et al. (2014a), however, here the countries of East, South and Southeast Asia were aggregated into one group due to their minor role in the deliveries to Finland. The detailed division for countries is available in table S4.

2.3 Potential of a crop to be cultivated in Finland

We assessed whether there is a physical constraint for a crop to be cultivated in a commercial scale in the northern climatic conditions in Finland. A crop that is defined as cultivable in Finland is currently cultivated, it has been traditionally cultivated or there are small scale field experiments that prove its cultivation potential in Finland. Based on this assumption all the crops included in the analysis were divided into three categories described in the Table S1. The consistency of the division was revised by a specialist in agricultural production of Finland (Professor Pirjo Peltonen-Sainio, personal communication, February 11, 2016).

2.4 Environmental indicators

The tons of traded products were converted into hectares of land used in the production in a source country. This was done using country, crop and time specific yields that are available in FAOSTAT (FAO, 2016). We assessed only the direct area used as cropland in primary production. We did not account for the land used in other phases of the production such as storage or processing. Total supply of calories was calculated for the food crops using the caloric conversion factors specific for each crop (FAO, 2001).

Water footprint is a widely used tool for analyzing water use. Water footprint has been classified into three categories: green, grey and blue water. Green water represents the rain water used for the crop to grow. Grey water is related to the pollution caused by the process and represents the amount of fresh water that is required to assimilate pollutants to meet specific water quality standards. Blue water represents the quantity of fresh water from rivers or lakes and the ground water used for irrigation (Mekonnen and Hoekstra, 2011). In this study we concentrated on the blue water i.e. the quantities of fresh water used for irrigation. We chose to focus on blue water because, especially in the water scarce areas, the fresh water resources are competed between various different users from ecosystems to infrastructure and agriculture, and therefore have an important role in the sustainability of the production. The quantities of crops imported to Finland were converted to blue water consumption based on the estimates of crop and country specific water use coefficients that were averaged over 1996-2005 (Mekonnen and Hoekstra, 2010).

Land use and blue water consumption were both translated into impacts on global biodiversity. Various methods have been developed to link the agricultural land use to biodiversity impacts (Gabel et al. 2016). In this study we applied the biodiversity characterization factors developed in two earlier studies (Chaudhary et al. 2016: Verones et al., submitted), due to their global applicability. Global biodiversity refers to the species richness (i.e. species number), threat level and portion of the geographical range of species at a certain location. Multiplying the resource use with characterization factors that describe an impact per resource use provides estimates of global biodiversity loss. The loss is expressed as the global potentially disappeared fraction of species in a year (gPDF a) and indicates how many species are at risk of extinction, i.e. the species might not only disappear at the location of impact but globally. The characterization factors for land use (Chaudhary et al., 2016) are based on countryside species-area relationships (SARs) for four animal classes (mammals, birds, amphibians and reptiles) from the IUCN database accessed in 2014 in 804 terrestrial ecoregions. By contrast, the characterization factors for water consumption (Verones et al., submitted) are a combination of two previous methods: one focuses on wetlands, translates water consumption to wetland area loss and follows a similar approach as the land-based methodology based on four animal classes from IUCN accessed in 2012 (Verones et al., 2013), and the other derives biodiversity loss by water consumption from the share of water limited net primary productivity for terrestrial plant species on a 0.5° grid (Pfister et al., 2009). The characterization factors were combined with crop production maps at a 5' resolution, valid for the year 2000, (Monfreda et al., 2008) to obtain country- and crop-specific characterization factors where authors did not provide them (Chaudhary et al., 2016).

2.5 Limitations of the study method

Water footprint coefficients used were averaged over 1996-2005 (Mekonnen and Hoekstra, 2010), which created two kinds of limitations to our study method. First, the study period in our analysis goes beyond this time frame from 1986 to 2011, and we used the averaged values for 1996-2005 for the whole time period. Second, the land use data we used were time-specific. This means that the yearly variations, such as lower yields, would translate into higher land use and higher biodiversity impacts while for water use the water-scarce years would not, as these are averaged out. Due to lack of data it was not possible to estimate in this study how much this would impact our results, but it is an important limitation to consider while analyzing the results.

The characterization factors for biodiversity impacts were derived from a limited number of taxa which are not necessarily representative for ecosystem functioning (Scherer and Pfister 2016). In addition, local PDFs might better describe the loss of functional biodiversity, whereas global PDFs used in this study indicate the risk of species extinction. Potentially disappeared species, if not globally extinct, might migrate back to a previously disturbed location if the disturbance, such as agricultural production, ceases (Scherer and Pfister 2016). Since different approaches and taxa were used to derive the characterization factors for land and water use, they are not necessarily compatible, but each is valuable on its own.

Consistency of the trade analysis data has been checked at the global level (Kastner et al., 2014a). The calculations in this study are based on the most consistent data available of agricultural production and bilateral trade. The approach assumes that the exports of a country are proportionally made up by domestic production and imports. This assumption is used, as information on the split between “re-exported” products and products used domestically is not available. In general, the assumption works well for homogeneous commodities that are traded in bulk, but can introduce inaccuracies for crop products with some kind of differentiation that might affect how they are exported vs. consumed domestically, e.g. if country A would mainly consume fair trade coffee that originates from country B while it mainly “re-exports” non-fair-trade coffee that originates from country C. Our focus is in the crop production. The method does not take into account pasture or grazing land due to their varying characteristics related to quality, productivity and human interference. The method also excludes planted fodder crops, such as alfalfa or clover because consistent production data in global scale are not available (Kastner et al., 2014a). Grazing lands account for the largest share of global human appropriation of land and inclusion of it in the analysis remains an important task for the future. The method does not include uncultivated food outside national statistics such as food from collecting wild mushrooms and berries despite its importance in Finnish cuisine (Schulp et al. 2014).

This method does not take into account the amount of waste created. The food wasted in the production accounts about 23% of the total cropland area of the global food supply and about half of this waste occurs in agriculture and postharvest phase (Kummu et al., 2012). This implies that the area estimates presented in this study are conservative and the land requirements in reality are larger.

Multi-cropping or having two or more harvests per year from one field is prevalent in many tropical countries making crop yields per year bigger than the statistics for a single crop show (Ray and Foley, 2013; Bruckner et al. 2015). Also extended fallow periods are standard parts of some especially low-input agricultural systems, making crop yields lower than statistics show. The approach used here assumes one harvest per year. If harvest frequency of a crop in an importing region is more than one – the world average potential crop harvest frequency is estimated at 1.32, while there is a harvest gap of about 57% (Ray and Foley 2013) – this would imply our results are overestimating the land use, on the contrary if the extended fallow periods of a crop in an importing region are more prevalent, this would suggest the approach used in this study is underestimating the land use.

3. Results

3.1 Finnish crop imports

Crop imports to Finland increased from 820 000 tons in 1986 to 2 360 000 tons in 2011 while total the per capita food supply increased only moderately (10%) (FAO, 2016). The share of imported crops of the total supply of calories increased from 12% in 1986 to 36% in 2011 (Fig 1). The imports fluctuated between years following changes in the economy. An economic recession in the early 1990s resulted in a decrease of the share of imports. In terms of cropland, the share of imports increased from 23% in 1987 to 41% in 2010, calculated in three-year means around the respective years. This means that the cropland area embedded in imports nearly doubled.

Finnish food exports also increased during the study period, though not in par with the trend of imports. In 1986 only 16% of the cropland area in Finland was cultivated for export products while the respective share in 2010 was 29% (Fig. 2). Cropland area within Finland decreased about 70 000 – 90 000 ha during the study period (Fig. 2) (OSF, 2016). At the same time cropland used for exports increased more than 140 000 ha. Our results show a mean Finnish cropland for 1986-2011 of 2 680 m2 cap^{-1} yr^{-1}. In 1992, the per capita consumption of cropland decreased to its lowest at 1 955 m2 cap^{-1}yr^{-1} due to the economic recession, but later on it increased again and stayed fairly unchanged during the rest of the study period. At the same time, agricultural efficiency increased significantly. For instance, the average global yield per unit area of land for cereals nearly doubled during 1986-2011 (FAO, 2016). The total demand of cropland area allocated to Finnish consumers remained surprisingly stable, as the increasing yields matched the changes in the consumption of land intensive foodstuff such as meat and dairy products (OSF, 2015).

The spectrum of importing regions changed over time. Around 2010, Europe and South-America were the principal regions of Finnish food imports. South-America accounted for over 24% of the total cropland imports in 2010. Finland has increased imports from European and former Soviet

Union countries from 49 000 ha to 284 000 ha during the study period (Table 1). Almost 40% of the imported cropland came from Europe. The diversity of the countries where Finland imports increased over time. Number of countries contributing to the Finnish food supply increased from 146 to 173 during 1986-2011. Detailed country level results of the imported land and blue water use can be found at the Table S4.

In terms of the cropland area required for farming, soybeans, coffee, rapeseed and wheat accounted for almost 60% of the Finnish imports in 2011 (Fig. 5). A total of eleven crops comprised around 80% of the imports between 1986 and 2011. Farming in general is restricted to crops that thrive in the local conditions. An important finding was that the imports to Finland barely increased for products that cannot be cultivated domestically in Finland, while most of the change was driven by importing products that could grow in Finland (Fig 6).

3.2 Impacts on land requirements, irrigation demand, and biodiversity

In the humid climate of northern Europe irrigation is needed only in special cases for certain drought sensitive crops. Therefore, the domestic blue water consumption is very small. Only less than 10% of the surface and groundwater used for irrigation of the crops analyzed comes from Finland (Table 1). The average blue water consumption in 1986-2011 related to crop supply in Finland was 25 m^3 cap^{-1} yr^{-1}, and it stayed relatively stable during the study period despite the increase of imports. In 1986 the USA was the most important country where Finland imported blue water from, but its share decreased from almost 30% to less than 10% of the total water consumption between 1987 and 2010. By 2010, Europe became the most important region of blue water imports to Finland (Table 1). From individual countries the most important were Spain, the USA, Thailand, India and Morocco (Fig 4).

We analyzed the threats to global biodiversity caused by land and blue water use of the Finnish supply of imported crops. Over 93% of the land use related biodiversity impacts of the Finnish food supply took place outside its border. Global biodiversity loss in Finland is small due to the fact that endemic species richness in Northern Europe is low (Kier et al., 2009). Figure 3 presents the results for land use related impacts for the year 2010. The most severe biodiversity impacts of land use were related to the crop imports from Brazil, India, Colombia and Indonesia. When assessing individual crops, the biggest biodiversity impacts were caused by the imports of coffee, cocoa, sugar, rubber and soybeans. The top 10 of the crop and country combinations causing the highest biodiversity impacts related to land use are presented in the Table S2. The imports of coffee from India, Colombia, Mexico and Brazil were related to the highest biodiversity threats.

The picture is quite different when analyzing the biodiversity impacts caused by the blue water use of the Finnish imports. Figure 4 presents the results for blue water use and the biodiversity impacts caused by the Finnish imports. Over 99% of the biodiversity impacts related to the blue water consumption took place abroad. The rice, and citrus fruits from Spain, USA and Egypt ranked the highest when analyzing the individual crop and country combinations related to the most severe biodiversity impacts related to blue water use (Table S3).

4. Discussion

4.1 Comparison of the results to earlier studies

Sandström et al. (2014) presented on average 30% larger yearly imported cropland areas from 1986 to 2007 compared to the estimates of this study. In the earlier analysis the three-year average of imported cropland of 2005-2007 was 830 000 ha, as compared to 540 000 ha presented in this study. The difference is explained mainly by pasture, which was included in Sandström et al. (2014) but excluded in this study. The imports to Finland grew steadily and considerably following similar trends as observed in the UK (De Ruiter et al., 2016), China (Qiang et al., 2013) and the world in general (Kastner et al., 2014a; Porkka et al., 2013). However the details of the globalization trends vary between countries. For example, Finland is less dependent on foreign cropland than the UK and the exports from Finland increased in the study period while the UK exports concurrently decreased (De Ruiter et al., 2016). The trend of globalization has been very strong, which must be carefully assessed and taken into account in the development of national and regional policies regarding food safety and security, environmental protection and rural development.

4.2 Displaced impacts

As the food imports to Finland increased from 1986 to 2011, also the potential of displaced adverse impacts to the environment increased. Land or water use alone are poor estimates of biodiversity pressure, since the impacts differ depending on local ecosystem characteristics (Chaudhary and Kastner, 2016). Pressures might be higher than the sum of both due to cascade effects (Loreau et al. 2001), or lower if both pressures act on the same species. In this research we assessed the environmental impacts with three environmental indicators: land use, blue water use and biodiversity impacts within production countries. The use of different indicators give distinct information on the environmental pressure and make a contribution to focus attention on different products and regions.

Imports to industrialized nations tend to drive adverse biodiversity impacts and even extinctions in tropical and biodiverse countries (Chaudhary and Kastner, 2016; Lenzen et al. 2012). Our results for Finland are similar to those for another European country Switzerland, where, interestingly regarding the human diet, imports of coffee and cocoa were estimated to prompt the highest teleconnected impacts related to land use on the global biodiversity (Chaudhary et al., 2016, Scherer and Pfister, 2016). In terms of land use, the most affected countries by the Finnish and Swiss imports were also similar: Brazil, India and Colombia; and in term of blue water use Spain and the USA (Fig 4). Although the details of the food supply patterns differ in Finland and in Switzerland, similar crops and world regions emerge in the results. Policy makers, food industries and consumers must pay attention to spatial hotspots and key products in order to further improve the sustainability of the global food system.

The environmental impacts of the food system are manifold and vary in time and space. Especially in large and internally diverse countries such as India or Brazil generalizations based on national total production are bound to be coarse. We need more detailed information from the production systems within countries to draw more reliable conclusions on impacts (Godar et al. 2015: Gabel et al. 2016). In reality, the environmental adverse impacts of agriculture vary at fine geographic scale within a country depending on soil types, distance from forest edge or streams, farming technology, weather patterns, etc. Country level studies such as this one constrain the analysis of impacts at the global scale and contribute to identifying regions and products that are potentially related to high environmental impacts. Reducing the imports from these regions would hardly be recommendable since they contribute to the local development in the exporting countries, however more focus should be put on the impacts of the production. For instance, importing environmentally labeled or certified products would be a way to avoid the potential biodiversity impacts in the most vulnerable regions.

To reduce the impacts policies targeted to producers, traders and producers should be implemented in parallel (Davis et al., 2016; Foley et al. 2011). Reduction of waste decreases the primary resource use (Kummu et al. 2012). In the production phase, sustainable intensification and improved precision can decrease the resource use and emissions from agriculture (Tilman et al. 2011), while eco-agriculture can offer co-benefits for agriculture and biodiversity conservation (Altieri, 1999; Scherr and McNeely, 2008). Consumer targeting approaches such as environmental certifications and labeling can help consumers make environmentally conscious choices (Galarraga Gallastegui, 2002). Dietary changes can contribute to a more sustainable food consumption and reduced pressure for biodiversity loss (Davis et al., 2016; Jalava et al. 2014; Pimentel and Pimentel, 2003;

Machovina et al. 2015). Reducing the resource intensive animal product consumption or lowering the consumption of beverages, such as coffee, with high environmental impact but with low nutritional value, would contribute to decreasing the environmental impact. Moreover, optimizing the transport logistics can assist in finding the least harmful and most sustainable locations for growing and processing the different food products to consumers who live in different parts of the world.

4.3 Sustainable food consumption in Finland

Finland has become strongly and increasingly connected to the global agricultural market both regarding imports and exports. Finland is no exception in this respect but rather a characteristic active partner in the economy of the ever globalizing world. In 2010 more than one third of the crops consumed in Finland were imported (Fig 2). Moreover, Finnish agriculture is dependent on various imported inputs to its production such as feed, fertilizers and fuels (Niemi et al., 2013). We showed that the production of crops that could be cultivated in Finland, particularly rapeseed, has shifted abroad. The drivers of change are diverse and they differ between crops. In the case of rapeseed, one possible explanation are the changes and variations in climate and the increased infections that affected the yields (Peltonen-Sainio et al., 2007) and contributed to the decline in domestic production. This suggest that climate change can also be an important driver and its role in driving the displacement of agricultural production in Finland has to be studied in more detail.

The crop production in Finland in general is very blue water efficient, because most of the production is rainfed. If domestic production is displaced by imports from countries with irrigated production this would contribute negatively to the overall water efficiency. This is contrary to the case with land use. The growing season in Finland is shorter and the yield levels are in general lower than in the rest of Europe. Imports from areas with higher yield to lower yields, such is the general case with Finland, leads to greater land use efficiency (Kastner et al., 2014). Finland is the world's northernmost cereal producing country and the northern location clearly constrains production. However, some the conditions are also beneficial to production, such as the long days with preferable light conditions in the summer months, rainfall that is sufficient for most crops and cold winters that restrict plant diseases. Finland has abundant land resources and, in theory, the potential to increase the cultivation of certain cereals and oil crops like rapeseed, which would serve to decrease the dependency on foreign production. Yet, the quantification or the economic feasibility of the cultivation potential in Finland was not assessed in this study. In a globalized world, various drivers such as prices and agricultural policies often impact the production decisions more than the physical cultivation potential.

Consumers in Finland are increasingly interested in knowing the origin of their food. Local food has been associated with quality, freshness and short transportation distances (Roininen et al., 2006). Despite the interest in local food, our study strengthens the earlier finding (Sandström et al., 2014) that at least until 2010, Finnish food imports continued to grow either directly for human nutrition or indirectly through the feed of animal products. Although locally produced or environmentally certified food is perceived favorably by many consumers, price and quality still tend to be the most decisive factors regarding food choices (Weatherell et al., 2003; Hartikainen et al., 2014). Obtaining affordable food and domestic production in sub-optimal conditions in Finland with high labor costs tend to be costly. Finland is a small open economy, which depends on the global market. Trying to close the Finnish borders from foreign agricultural products is unlikely to be successful nor even desirable from any broad perspective. With the increasing agricultural globalization, it is important to increase consumers and decision-makers knowledge on the displaced environmental impacts, in order to promote more sustainable food system both in the consuming and producing countries.

5. Conclusions

Our results for Finland reproduce the pattern of a high-income industrialized country displacing environmental pressure through global trade. Comparisons between other European countries indicate national specifics. Displacement trends not universal, and new research is needed in order to better understand national trends and their case-specific drivers. The approach we used can be applicable to other countries to assess and demonstrate the environmental impacts of food consumption as they spread across national borders.

A spatial separation of consumption from production disconnects consumers from their food sources. It becomes difficult for consumers to be aware of the environmental impacts related to patterns of their consumption. The imports of food consumed in Finland nearly doubled from 1986 to 2011, especially concerning products that could also be grown in Finland and have previously been mainly produced domestically. Since imports come mainly from areas with higher yields, international trade has led to a greater land use efficiency. However, when importing from areas with high biodiversity the ecological impacts are a tradeoff that should be considered. This highlights the need to use multiple metrics in assessing the impacts of globalization. Most of the biodiversity impacts caused by the Finnish food consumption are taken place outside Finnish borders. It is important to make sure that the policies promoting sustainable consumption at local level do not result in the displacement of the pressures into environmentally more vulnerable locations.

We presented the links between country level food supply and the externalized global impacts using various environmental indicators (land use, water use and biodiversity impacts). The use of multiple indicators can contribute to a more holistic decision-making regarding trade and the environment. For instance, the countries and crops related to the most severe biodiversity impacts in our analysis were different when analyzing the land or water use. Assessing multiple indicators can guide environmentally aware consumers, producers, retailers and policymakers to focus their attention to specific commodities and promote solutions to sustainable production and consumption locally as well as globally.

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7. References

Altieri, M. A., 1999. The ecological role of biodiversity in agroecosystems. Agr. Ecosyst. Environ., 74(1), pp. 19-31.

Bruckner, M., Fischer, G., Tramberend, S., Giljum, S., 2015. Measuring telecouplings in the global land system: A review and comparative evaluation of land footprint accounting methods. Ecol. Econ., 114, pp. 11–21. doi:10.1016/j.ecolecon.2015.03.008

Chaudhary, A., Kastner, T. 2016. Land use biodiversity impacts embodied in international food trade. Global Environ. Change, 38, pp. 195-204.

Chaudhary, A., Pfister, S., Hellweg, S., 2016. Spatially Explicit Analysis of Biodiversity Loss due to Global Agriculture, Pasture and Forest Land Use from a Producer and Consumer Perspective. Environ. Sci. Technol., 50, pp. 3928–3936.

Cuypers, D., Geerken, T., Gorissen, L., Lust, A., Peters, G., Karstensen, J., Prieler, S., Fisher, G., Hizsnyik, E., Van Velthuizen, H., 2013. The impact of EU consumption on deforestation: Comprehensive analysis of the impact of EU consumption on deforestation. Bruss. Eur. Union Tech. Report–2013–063.

Davis, K. F., Gephart, J. A., Emery, K. A., Leach, A. M., Galloway, J. N., D'Odorico, P. 2016. Meeting future food demand with current agricultural resources. Glob. Environ. Chang., 39, pp. 125-132.

D'Odorico, P., Carr, J.A., Laio, F., Ridolfi, L., Vandoni, S., 2014. Feeding humanity through global food trade. Earth's Future 2, pp. 458–469. doi:10.1002/2014EF000250

FAO, 2016. Food and Agriculture Organization Statistics Division FAOSTAT. http://faostat.fao.org/. Accessed 6.4.2016.

FAO, 2001. FOOD BALANCE SHEETS - A Handbook. Food and Agriculture Organization of the United Nations, Rome.

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., Mueller, N. D., O'Connel, C., Ray, D. K., West, P. C., Balzer, C., Bennett, E. M., Carpenter, S. R., Hill, J., Monfreda, C., Polasky, S., Rockström, J., Sheehan, J., Siebert, S., Tilman, D., Zaks, D. P. M. 2011. Solutions for a cultivated planet. Nature, 478(7369), pp. 337-342.

Gabel, V. M., Meier, M. S., Köpke, U., Stolze, M. 2016. The challenges of including impacts on biodiversity in agricultural life cycle assessments. J. Environ. Manage., 181(1), pp. 249–260.

Galarraga Gallastegui, I. 2002. The use of eco-labels: a review of the literature. Eur. Environ., 12(6), pp. 316-331.

Godar, J., Persson, U. M., Tizado, E. J., Meyfroidt, P.,2015. Towards more accurate and policy relevant footprint analyses: Tracing fine-scale socio-environmental impacts of production to consumption. Ecol. Econ., 112, pp. 25-35.

Haberl, H., Erb, K.H., Krausmann, F., Gaube, V., Bondeau, A., Plutzar, C., Gingrich, S., Lucht, W., Fischer-Kowalski, M., 2007. Quantifying and mapping the human appropriation of net primary production in earth's terrestrial ecosystems. Proc. Natl. Acad. Sci. 104, pp. 12942–12947.

Hartikainen, H., Roininen, T., Katajajuuri, J. M., Pulkkinen, H. 2014. Finnish consumer perceptions of carbon footprints and carbon labelling of food products. J. Clean. Prod. 73, pp. 285-293.

Hoekstra, A.Y., Chapagain, A.K., 2008. Water Saving Through International Trade in Agricultural Products, in: Globalization of Water: Sharing the Planet's Freshwater Resources. pp. 31–50.

Jalava, M., Kummu, M., Porkka, M., Siebert, S., Varis, O. 2014. Diet change—a solution to reduce water use? Environ. Res. Lett., 9(7), 074016.

Kastner, T., Kastner, M., Nonhebel, S., 2011. Tracing distant environmental impacts of agricultural products from a consumer perspective. Ecol. Econ., 70, pp. 1032–1040.

Kastner, T., Erb, K.-H., Haberl, H., 2014a. Rapid growth in agricultural trade: effects on global area efficiency and the role of management. Environ. Res. Lett. 9, 034015.

Kastner, T., Schaffartzik, A., Eisenmenger, N., Erb, K.-H., Haberl, H., Krausmann, F., 2014b. Cropland area embodied in international trade: Contradictory results from different approaches. Ecol. Econ., 104, pp. 140–144. doi:10.1016/j.ecolecon.2013.12.003

Kier, G., Kreft, H., Lee, T. M., Jetz, W., Ibisch, P. L., Nowicki, C., Mutke, J., Barthlott, W. 2009. A global assessment of endemism and species richness across island and mainland regions. Proc. Natl. Sci. Unit. States. Am., 106(23), pp. 9322-9327.

Koskela, S., Mäenpää, I., Seppälä, J., Mattila, T., Korhonen, M.-R., 2011. EE-IO modeling of the environmental impacts of Finnish imports using different data sources. Ecol. Econ., 70, pp. 2341–2349.

Kummu, M., De Moel, H., Porkka, M., Siebert, S., Varis, O., Ward, P.J., 2012. Lost food, wasted resources: Global food supply chain losses and their impacts on freshwater, cropland, and fertiliser use. Sci. Total Environ., 438, pp. 477–489.

Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., Geschke, A. 2012. International trade drives biodiversity threats in developing nations. Nature, 486(7401), pp. 109-112.

Liu, J., Hull, V., Batistella, M., DeFries, R., Dietz, T., Fu, F., Hertel, T.W., Izaurralde, R.C., Lambin, E.F., Li, S., Martinelli, L.A., McConnell, W.J., Moran, E.F., Naylor, R., Ouyang, Z., Polenske, K.R., Reenberg, A., de Miranda Rocha, G., Simmons, C.S., Verburg, P.H., Vitousek, P.M., Zhang, F., Zhu, C., 2013. Framing Sustainability in a Telecoupled World. Ecol. Soc., 18. doi:10.5751/ES-05873-180226

Loreau, M., Naeem, S., Inchausti, P., Bengtsson, J., Grime, J. P., Hector, A., Hooper, D.U., Huston, M. A., Raffaelli, D., Schmid, B., Tilman, D., Wardle, D. A. 2001. Biodiversity and ecosystem functioning: current knowledge and future challenges. Science, 294(5543), pp. 804-808.

MacDonald, G.K., Brauman, K.A., Sun, S., Carlson, K.M., Cassidy, E.S., Gerber, J.S., West, P.C., 2015. Rethinking Agricultural Trade Relationships in an Era of Globalization. BioScience 65, pp. 275–289. doi:10.1093/biosci/biu225

Machovina, B., Feeley, K. J., Ripple, W. J., 2015. Biodiversity conservation: The key is reducing meat consumption. Sci. Total Environ., 536, pp. 419-431.

Mattila, T., Seppälä, J., Nissinen, A., Mäenpää, I., 2011. Land use impacts of industries and products in the Finnish economy: a comparison of three indicators. Biomass and Bioenergy, 35(12), pp. 4781-4787.

Mäenpää, I., Siikavirta, H., 2007. Greenhouse gases embodied in the international trade and final consumption of Finland: an input–output analysis. Energ. Pol., 35, pp. 128–143.

Mekonnen, M.M., Hoekstra, A.Y., 2010. The green, blue and grey water footprint of crops and derived crop products, Value of Water Research Report Series No. 47,. UNESCO-IHE, Delft, the Netherlands.

Mekonnen, M.M., Hoekstra, A.Y., 2011. The green, blue and grey water footprint of crops and derived crop products. Hydrol. Earth Syst. Sci., 15, pp. 1577–1600.

Meyfroidt, P., Rudel, T.K., Lambin, E.F., 2010. Forest transitions, trade, and the global displacement of land use. Proc. Natl. Acad. Sci. Unit. States. Am., 107, pp. 20917–20922. doi:10.1073/pnas.1014773107

Monfreda, C., Ramankutty, N., Foley, J.A., 2008. Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. Glob. Biogeochem. Cycles 22.

Niemi, J., Knuuttila, M., Liesivaara, P., Vatanen, E., 2013. Suomen ruokaturvan ja elintarvikehuollon nykytila ja tulevaisuuden näkymät. Natual Resources Institute Finland. MTT Report 80. 67p. (In Finnish). http://jukuri.luke.fi/handle/10024/438291

OSF, Official Statistics of Finland, 2016. Utilised Agricultural Area [e-publication]. Helsinki: Natural Resources Institute Finland. http://www.stat.fi/til/kaoma/index_en.html. Accessed: 6.4.2016.

OSF, Official Statistics of Finland, 2015. Balance Sheet for Food Commodities. Helsinki: Natural Resources Institute Finland. http://stat.luke.fi/en/balance%20sheet%20for%20food%20commodities. Accessed: 6.4.2016.

Peltonen-Sainio, P., Jauhiainen, L., Hannukkala, A., 2007. Declining rapeseed yields in Finland: how, why and what next? J. Agric. Sci., 145, pp. 587–598.

Peters, G. P., Hertwich, E. G., 2008. CO2 embodied in international trade with implications for global climate policy. Environ. Sci. Tech., 42(5), pp. 1401-1

Pfister, S., Koehler, A., Hellweg, S., 2009. Assessing the Environmental Impacts of Freshwater Consumption in LCA. Environ. Sci. Tech., 43 (11), pp. 4098–4104.

Pimentel, D., Pimentel, M. 2003. Sustainability of meat-based and plant-based diets and the environment. Am. J. Clin. Nutr., 78(3), pp. 660S-663S.

Porkka, M., Kummu, M., Siebert, S., Varis, O., 2013. From Food Insufficiency towards Trade Dependency: A Historical Analysis of Global Food Availability. PLOS ONE, 8, e82714. doi:10.1371/journal.pone.0082714

Qiang, W., Liu, A., Cheng, S., Kastner, T., Xie, G., 2013. Agricultural trade and virtual land use: The case of China’s crop trade. Land Use Pol., 33, pp. 141–150. doi:10.1016/j.landusepol.2012.12.017

R Core Team, 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Ray, D. K., Foley, J. A. 2013. Increasing global crop harvest frequency: recent trends and future directions. Environ. Res. Lett, 8(4), 044041.

Roininen, K., Arvola, A., Lähteenmäki, L., 2006. Exploring consumers' perceptions of local food with two different qualitative techniques: Laddering and word association. Food Qual. Prefer., 17, pp. 20–30.

De Ruiter, H. de, Macdiarmid, J.I., Matthews, R.B., Kastner, T., Smith, P., 2016. Global cropland and greenhouse gas impacts of UK food supply are increasingly located overseas. J. R. Soc. Interface 13, 20151001. doi:10.1098/rsif.2015.1001

Rulli, M. C., Saviori, A., D'Odorico, P., 2013. Global land and water grabbing. Proc. Natl. Acad. Sci. Unit. States. Am., 110(3), pp. 892-897.

Sandström, V., Saikku, L., Antikainen, R., Sokka, L., Kauppi, P., 2014. Changing impact of import and export on agricultural land use: the case of Finland 1961–2007. Agric. Ecosyst. Environ., 188, pp. 163–168.

Scherer, L., Pfister, S. 2016. Global Biodiversity Loss by Freshwater Consumption and Eutrophication from Swiss Food Consumption. Environ. Sci. Technol. doi:10.1021/acs.est.6b00740

Scherr, S. J., McNeely, J. A., 2008. Biodiversity conservation and agricultural sustainability: towards a new paradigm of 'ecoagriculture'landscapes. Phil. Trans. Roy. Soc. Lon. B. Biol. Sci., 363(1491), pp. 477-494.

Schulp, C. J. E., Thuiller, W., & Verburg, P. H. 2014. Wild food in Europe: A synthesis of knowledge and data of terrestrial wild food as an ecosystem service. Ecol. Econ., 105, pp. 292-305.

South, Andy 2011 rworldmap: A New R package for Mapping Global Data. The R Journal Vol. 3/1 :35-43.

Suweis, S., Carr, J. A., Maritan, A., Rinaldo, A., D'Odorico, P. 2015. Resilience and reactivity of global food security. Proc. Natl. Acad. Sci. Unit. States. Am., 112(22), pp. 6902-6907.

Tilman, D., Balzer, C., Hill, J., Befort, B. L. 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. Unit. States. Am., 108(50), pp. 20260-20264.

Verones, F., Saner, D., Pfister, S., Baisero, D., Rondinini, C. and Hellweg, S., 2013. Effects of Consumptive Water Use on Biodiversity in Wetlands of International Importance. Environ. Sci. Tech., 47 (21), pp. 12248–12257.

Verones, F., Pfister, S., Zelm, R., van Hellweg, S., submitted. Biodiversity impacts from water consumption on a global scale for use in life cycle assessment. Int J Life Cycle Assess.

Weatherell, C., Tregear, A. Allinson, J. 2003. In search of the concerned consumer: UK public perceptions of food, farming and buying local. J. Rural Stud., 19(2), pp. 233-244.

WWF Finland, 2012. Suomen vesijalanjälki - Globaali kuva suomalaisten vedenkulutuksesta. WWF Suomi (In Finnish).

Yu, Y., Feng, K., Hubacek, K., 2013. Tele-connecting local consumption to global land use. Glob. Environ. Change 23, pp. 1178–1186. doi:10.1016/j.gloenvcha.2013.04.006

Table 1. Land and blue water use of the Finnish consumption by domestic production and importing regions. Numbers presented as three-year means around the respective years.

	Land use				**Blue water use**			
	1987		**2010**		**1987**		**2010**	
	(1000 ha)	**(%)**	**(1000 ha)**	**(%)**	**(1000 m^3)**	**(%)**	**(1000 m^3)**	**(%)**
Finland	1080	77	847	59	8865	7	9711	8
EU 15 +	26	2	131	9	18518	15	42367	36
FSU and other Europe	23	2	153	11	2245	2	3182	3
North America	85	6	20	1	32593	27	9994	8
South America	95	7	139	10	8783	7	14783	13
Central America and Caribbean	28	2	24	2	2862	2	2204	2
Northern Africa and Western Asia	7	0	4	0	24291	20	6449	5
Sub-Saharan Africa	35	2	61	4	12062	10	8980	8
South and Eastern Asia	21	1	48	3	5180	4	19374	16
Oceania	3	0	9	1	7339	6	726	1
Total	**1403**		**1436**		**122738**		**117770**	

Figures

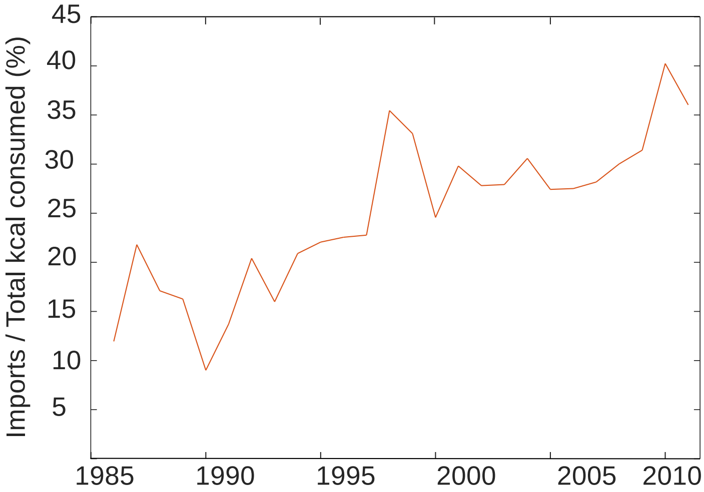

Figure 1*. Share of imports of the total crop consumption in Finland presented in calories consumed. Crop products include the direct consumption of crops and the indirect consumption of crops through animal feed.*

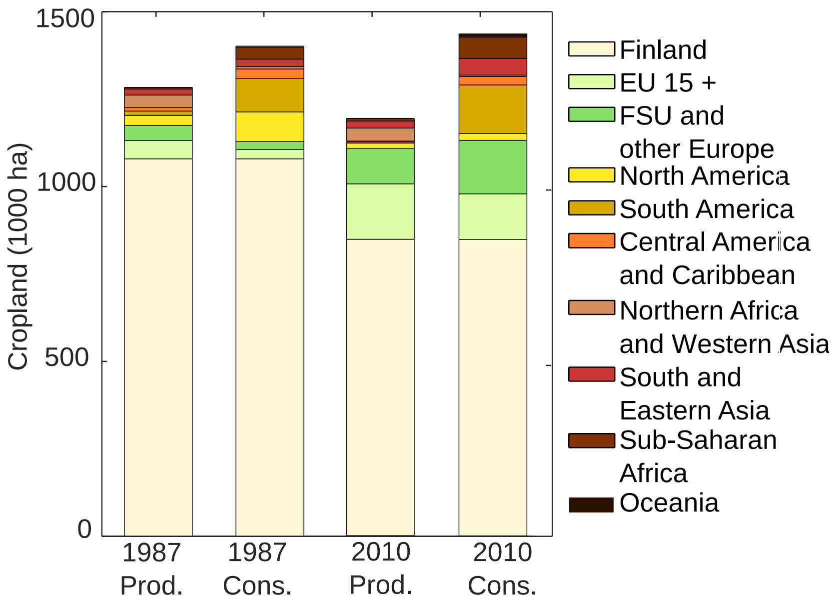

Figure 2. *Use of domestic and foreign cropland in Finland's food supply. Production perspective refers to the area of domestic cropland used for domestic consumption and exports. Consumption perspective refers to the area consumed from domestic production and imports (Kastner et al., 2011). Results are presented in three-year means around the respective years.*

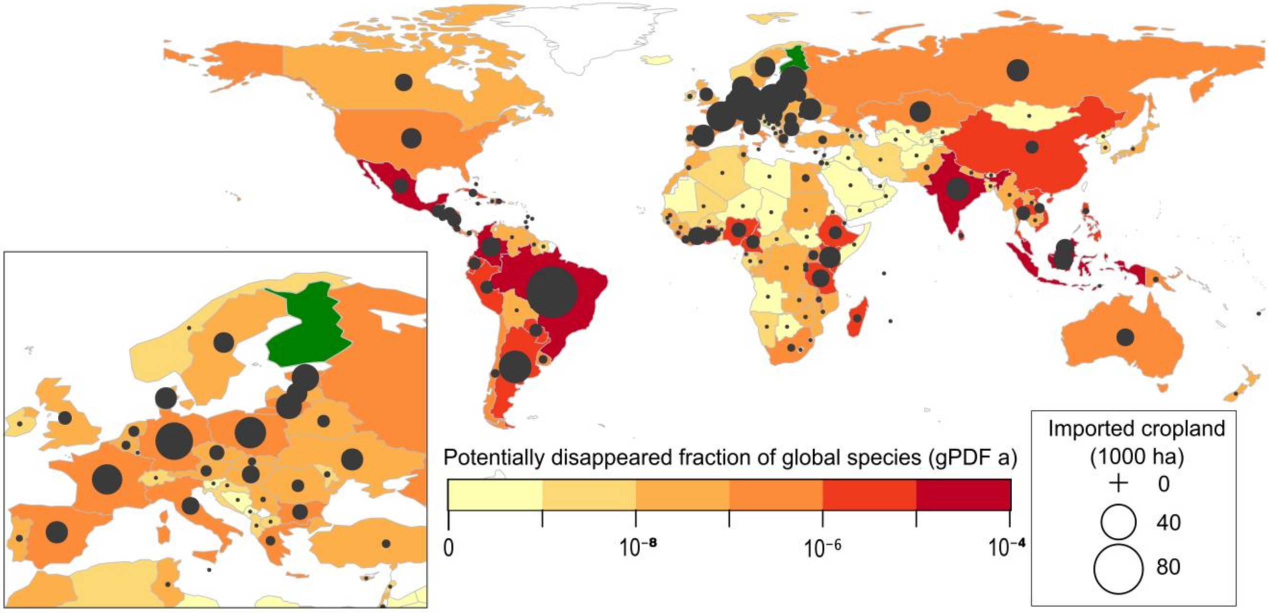

__Figure 3.__ Imported cropland and the impacts on global biodiversity in 2010. Bubbles represent the "imported" cropland and the color of the countries represents biodiversity impacts caused by land use (values presented as three-year means of 2009-2011).

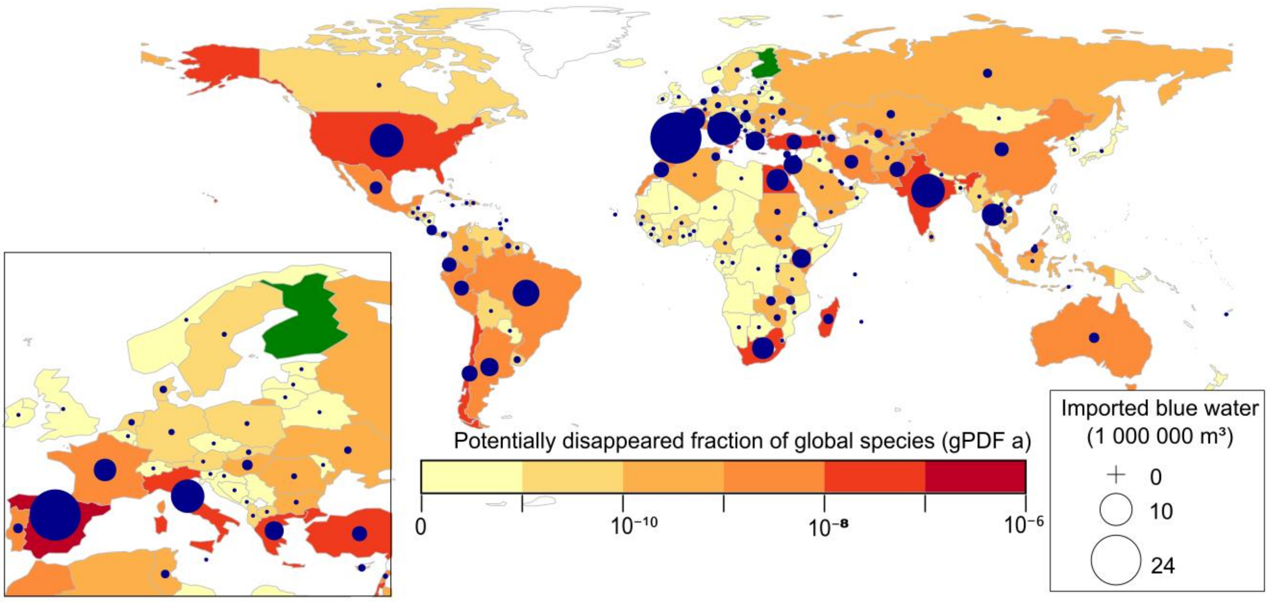

__Figure 4.__ Imported blue water and the impacts on global biodiversity in 2010. Bubbles represent the quantities of imported blue water and the color of the countries represents biodiversity impacts caused by blue water use (values presented as three-year means of 2009-2011).

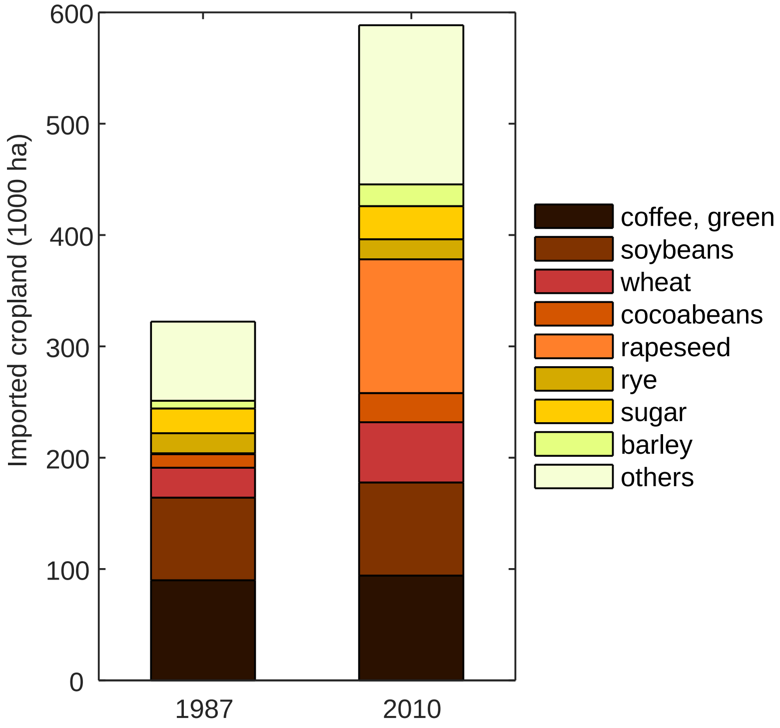

Figure 5. *Imported cropland to Finland by crop type.*

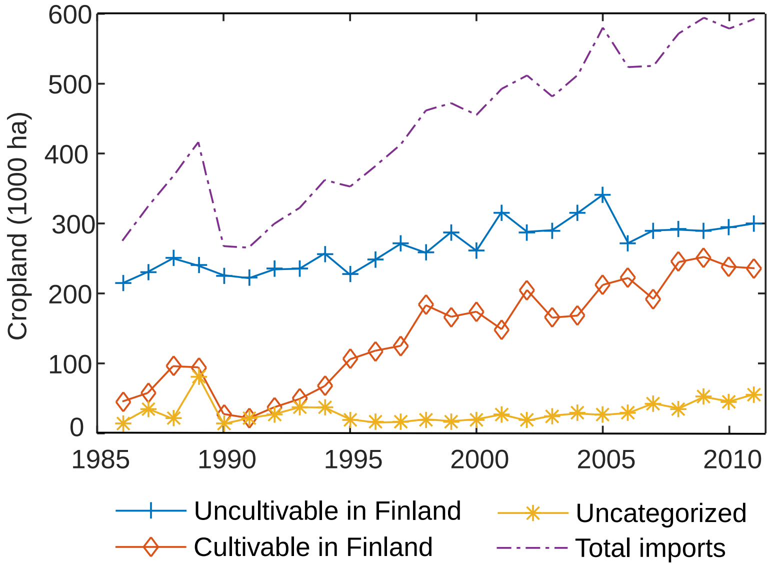

Figure 6. *Imported cropland in relation to their potential to be cultivated in Finland; for the crops included in each category refer to Table S1.*